An Approach to Wheel Loader Bucket Raise Time Detection

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ABSTRACT: An approach to wheel loader bucket raise time recognition based on mathematical algorithms is presented in this communication. Wheel loader bucket raise time is one of the most essential parameters in total cycling time, which provides the work efficiency for wheel loader. Wheel loader bucket raise time is detected by the application of a simple mathematical algorithm after wavelet transform. Firstly, a signal of wheel loader total cycling time signal (original signal) which includes bucket raise time, bucket dump time and bucket lower time was selected, and then it was processed by the wavelet transform. Secondly, we could get wavelet decomposition approximation signal a5, and mathematical algorithm was implemented at simple computational cost by signal form, which detected the singular points from signal a5. Finally, original signal based on threshold decision combined singular points to detect the onset point and offset point of bucket raise segment in original signal. And then we could get bucket raise time. The records were from a loader factory online detection test. The result demonstrated that the detection rate is more than 95%. This study implemented automatic detection of wheel loader bucket raise time.

Keywords: wheel loader; bucket raise time; wavelet transform; mathematical algorithm

1 INTRODUCTION

Wheel loader bucket raise time is usually the most essential parameter in wheel loader total cycling time which includes bucket raise time, bucket dump time and bucket lower time. Bucket raise time provides the work efficiency for wheel loader, which is the fundamental of automatic total cycling time signal analysis. Before the online detection, we obtained the bucket raise time by manually operated digital timer during the loader factory testing, which was not accurate and convenient. From now on, the factory is going to use hydraulic pressure sensor to measure the pressure of wheel loader hydraulic working system during factory acceptance and achieve the data by LabVIEW program. Therefore, we can achieve the wheel loader total cycling time signal that we called original signal and it is shown in Figure 1. So, seeking for a reliable bucket raise time detection algorithm is essential for automatic online detection. As we know, the signal detection approaches have been proposed for over decades, e.g., wavelet transforms [1], hidden Markov models [2], matched filter [3], derivative based algorithms [4], Hilbert transform [5], artificial neural networks [6], genetic algorithm [7], support vector machine [8], syntactic methods [9], length and energy transforms [10], adaptive filtering [11], etc. However, some approaches such as hidden Markov models, artificial neural networks, genetic algorithm and adaptive filtering need samples training or reference signal before signal detection, which makes computation complex. Therefore, an approach without samples training or reference signal is desirable. Besides, most methods have common problems in parameter number, and operation, and complicated steps are too much for the signal detection. Using these methods will increase the difficulty of online real time implementation. So, finding an approach with high accuracy and speed to bucket raise time detection is remarkable.

In this study, a reliable approach based on accuracy mathematical algorithm of wheel loader bucket raise time detection was proposed. Firstly, original signal...
was processed by wavelet transform and achieved the wavelet decomposition approximation signal a5. Then, signal a5 was detected by mathematical algorithm, after the singular points were obtained. Finally, combine the singular points with original signal points processed by threshold, and bucket raise segment’s onset point and offset point were achieved. The time of onset and offset intervals were easily achieved.

Figure 1. Total cycling time signal of wheel loader.

2 THEORY

2.1 Wavelet transform

The wavelet transform is a new method of signal analysis tools that is also called mathematical microscope. The basic idea of the wavelet transform is scaling and translation. The source of the wavelet transform could be traced back to 1910 when Haar put forward the standard orthogonal wavelet bases. In 1938, Littlewood Paley constructed L-P theory which is based on Fourier series. In 1984, Morlet introduced the concept of wavelet to decompose the collected signal. In the same year, based on the research acquired from Morlet, Grossman analyzed signal in certain scaling and translation. Therefore, Grossman was the pioneer who used wavelet transform in practical application. In 1986, the famous mathematician Meyer was creatively constructed a smooth function which has a certain attenuating property whose translation and second order scaling constitute the standard orthogonal basis. One year later, Mallat, a signal processing engineer, created a new algorithm which combined multi-scale with wavelet transform, which is called Mallat algorithm. In the same year, Daubechies constructed limited set of orthogonal wavelet base. Therefore, until 1987, the theory basis of wavelet transform was preliminary established.

The wavelet transform which has been used successfully in a broad range of applications, inherited and developed the Fourier transform in a short time and overcome its shortcomings. Therefore, wavelet transform has been used to solve problems in signal processing, especially in recent years, such as compression, filtering, time frequency analysis, signal to noise separation, pattern recognition and multi-scale edge detection, which can achieve reliable analysis and process result. The wavelet transform is a linear operation which decomposes signals into a quantity of scales that is related to frequency components and deals each scale with certain resolution. It has a multi-resolution automatic focusing and characteristics of direction selectivity.

The wavelet transform usually provides optimal decomposition of original signal for each testing wheel loader which uses a short time interval for evaluating higher frequencies and a long time interval for lower frequencies. Therefore, high frequency components of short duration can be achieved speedily by wavelet transform. On the other hand, decomposing signals at various resolutions is one of the advantages to the wavelet transform. A family of wavelet cluster analysis signals in the time frequency domain what is achieved by applying a scaling factor and a translation factor from the basic prototype wavelet function.

The wavelet transform which is essential in signal process is defined as equation (1).

\[
W_x(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t) \Psi \left( \frac{t-b}{a} \right) dt
\]

Where \(W_x\)=wavelet transform; \(\Psi=\)shifted and scaled version of a prototype wavelet; \(a=\)scale factor; \(b=\)translation factor. In the equation (1), \(\Psi\) is used as a fundamental for wavelet decomposition of the processed signal. One of the essential standards of a prototype wavelet has the ability to absolutely reconstruct the signal from the wavelet decomposition. If a prototype wavelet \(\Psi_2(t)\) is the derivative of a smoothing prototype \(\Psi_1(t)\). The signal at scale a is defined as equation (2).

\[
\frac{1}{\sqrt{a}} \int_{-\infty}^{\infty} x(t) \Psi_2 \left( \frac{t-b}{a} \right) dt = -a \frac{d}{db} \int_{-\infty}^{\infty} x(t) \Psi_1(t-b) dt
\]

Where \(\Psi_1,(t)\)=scale version of the smoothing function and it is defined as equation (3).

\[
\Psi_1,(t) = \frac{1}{\sqrt{a}} \Psi_1 \left( \frac{t}{a} \right)
\]

2.2 Wavelet selection

The selection of relevant wavelet is an essential task before processing signals. The use of the wavelet transform has gained similar analyses, but the accuracy and efficiency depend on the similarity between wavelet and the signal which is going to be processed. There are a number of wavelet families, e.g., Haar, Daubechies, symlets, coiflets, biorthogonal, Reverse biorthogonal, Meyer, Discrete approximation of Meyer, Gaussian, Mexican hat, Morlet, Shannon, etc. and several other real and complex wavelets. However,
after comparing wavelet with the signal, we found that coiflets wavelet is the best, which is more similar to original signal and gives more accurate details than other wavelet families. Moreover, coif wavelet family has coif1 to coif5 and they all have obvious points. The coif family is shown in Figure 2.

As shown in Figure 2, we can conclude that the wavelet after coif3 is unfit for original signal which wavelet with an edge waveform is too sharp and far away from original signal. Therefore, after comparing coif1 with coif2 in processing original signal, we obtained that coif1 has a better result. In the comparison, the signal decomposed by coif1 had more obvious singular points than coif2. After compared with the result of decomposition, we concluded that the best decomposition level is 5. After comparison test, we decided to use coif1 wavelet which is the most similar wavelet to original signal with the best decomposition level 5 for decomposing original signal in this study.

2.3 Mathematical algorithm

In previous study of signal processing and detection, significant characters of signals are used to estimate whether the signals are useful. From a detailed study, we found that significant characters of signals were achieved by efficient and accurate algorithm.

In this study, we were going to find the onset and offset point of bucket raise time. From Figure 1, we could achieve that either the onset point or the offset point are in the valley of the signal. Therefore, finding a quick mathematical algorithm with accuracy for onset point and offset point in bucket raise segment is remarkable. During the process of original signal with wavelet transform in coif1 wavelet and level-5 decomposition, we could achieve the wavelet decomposition approximate signal $a_5$ which has the same peak and valley as original signal. Figure 3 shows the signal $a_5$.

The signal $a_5$ has an edge waveform compared with the original signal and its valley points are obvious and can be easily detected. It can decrease a lot of calculation in mathematical algorithm and increase detection efficiency. The signal $a_5$ compared with original signal is shown in Figure 4.

Enlarge onset and offset points of bucket raise time segment in wheel loader total cycling time in Figure 4. Then we could achieve that the valley points in signal $a_5$ are obvious, which are also the singular points. The onset point and offset point belong to singular points which are showed in Figure 5 and 6.

In Figure 5, we could conclude that the point between 600 ms to 620 ms is onset point that the former point has a smoother pressure gradient than the point
we choose, at a small hydraulic pressure less than 0.5 Mpa (mega pascal). In practice, when the hydraulic pressure power is less than 1 Mpa, the pressure is less than the threshold value of drive, so this pressure could not drive the bucket. Therefore, we can acknowledge that the point we choose is the onset point of bucket raise time segment.

In Figure 6, we could conclude that the singular point between 1140 ms to 1160 ms is the offset point. We can also conclude that around offset point, the gradient before this point is steep and after that is gentle, which means the bucket raise time segment is over. And we could find that the offset point in original signal has a small pressure which is smaller than 2 Mpa. Therefore, we can acknowledge that the point between 1140 ms to 1160 ms is the offset point of bucket raise time segment.

Values of onset and offset points of bucket raise time segment are usually longer than the time of bucket dump and bucket which are less than 4 seconds. Therefore, it is necessary to achieve an algorithm which can detect the singular points and compute the value between a pair of singular points that every segment regards only one pair of singular points as onset point and offset point. In the algorithm, we combine the original signal with signal a5 based on threshold to ensure that either bucket raise time segment or dump segment and lower segment have only one pair of singular points, which only has two points, onset point and offset point, and then eliminate this four points about bucket dump and lower time segment. Therefore, we could achieve the position of onset and offset points in axes of time of bucket raise time segment and calculate its time.

Using the mathematical algorithm based on the signal a5, we can achieve the speed of the singular points and combine with the threshold decision in original signal. Use the algorithm to process signal a5, and onset point and offset point of bucket raise time segment can be obtained.

2.4 Data

Signals of total cycling time of wheel loader demanded for analysis were collected from online detection test of Liugong wheel loader factory, where the bucket raise time, bucket dump time and bucket lower time had been measured by manual work and recorded the values of time in text file before. From now on, the data will be collected by LabVIEW program which is based on working hydraulic pressure system of wheel loader, and then saved it in online database [12].

The working hydraulic pressure of wheel loader is the pressure of driving wheel loader bucket which is always called working pressure. The pressure signals showed working state of bucket and analyzing the signal could be able to achieve bucket raise time and wheel loader total cycling time. But, the signal processing is more complex than manual work for achieving the bucket raise time. So, processing signal and achieving the points we need is the key point in this study.

3 METHODS

In this study, we were going to extract the original signal, and the purpose is to select and achieve relevant singular points and then use these points to calculate bucket raise time.

3.1 Noise interference

In most of signal processing, we should process the raw signal at first time, which contains a lot of different types of noises. In practice, baseline drift and power frequency interference are the two main noises of signals which are collected from sensor. The baseline drift has an influence on signal that makes normal baseline position float up and down. The power frequency interference reduces the signal to noise ratio. But in the test, we achieved that the two main noise interferences did not have a significant influence on the position of original signal’s valley points and signal a5’s singular points during the process. In this study, the major objective was achieving the bucket raise time rather than the investigation of waveform. The values of bucket raise time remain unchanged whether the noise is removed or not. Therefore, it is concluded that noise interference did have a significant influence on the value of bucket raise time. Moreover, we will not introduce the removal of the noise in this paper.

3.2 Methodology

In this study, the overall process of bucket raise time detection combining wavelet transform with mathematical algorithm was divided into the following stages:

(1) We used LabVIEW program to collect data from hydraulic pressure sensor which measured the working hydraulic pressure system of wheel loader total cycling time signal, and it was also called original signal in this study.

(2) The original signal was decomposed by coif1 wave form and the decomposition level was 5 in MATLAB wavelet toolbox. Then we could achieve wavelet decomposition approximation of signal a5, which was also called signal a5.

(3) The signal a5 was detected by mathematical algorithm after we could achieve a number of singular points. These singular points include three segments’ onset point and offset point. Next, combining with original signal based on threshold decision, only two singular points could be left which were bucket raise time segment’s onset point and offset point.

(4) According to the pair of singular points, we could obtain bucket raise time.
The block diagram of the methodology and its stages are shown in Figure 7.

3.3 Collection of original signal

The original signal is the pressure data collected by pressure sensor from hydraulic pressure working system of wheel loader. However, the pressure data is not recognized by IPC (industry personal computer). The data of pressure sensor output analog signal, but most IPC can only accept digital signal. In industry, the analog signal is always converted to digital signal using DAQ card (data acquisition card). In order to convert the analog signal to digital signal which could be recognized by IPC, we should design a circuit board with DAQ to complete data conversion and solve the IPC data problem at the same time.

The accuracy of pressure sensor usually changes when testing environment condition. Therefore, the pressure sensor should be checked before collecting original signal. To solve this problem, we use standard gauges of pressure and linear function which is the algorithm principle of pressure sensor and calibrate the pressure sensor.

To solve the problems of hardware, the IPC also needs a software program to collect converted sensor signals. LabVIEW software is a graphic programming virtual instrument which is good at connecting with instrument. Therefore, we choose LabVIEW software in IPC to gather the converted digital data from DAQ card and communicate with database.

3.4 Procession of original signal

To process the original signal by wavelet transform, the MATLAB software was adopted. MATLAB software is a data analysis, algorithm investigation and numerical computation development environment, which has a lot of toolboxes with functional diversity including wavelet toolbox. Therefore, we were going to use MATLAB and wavelet toolbox to decompose the original signal with coif1 wavelet and decomposition in level 5, and then we could achieve signal a5 which has obvious singular points. The singular points smaller than 2 Mpa belong to onset or offset points in the three segments of bucket movement and will be detected easily.

3.5 Detection of bucket raise time

Since the mathematical algorithm technique is entirely based on principles, it was usually used in achieving specific points and lines as an excellent way of signal processing. After processing of original signal, we were able to get the singular points by mathematical algorithms, but some of them are excess. Therefore, based on the threshold decision, most of the excess singular points would be canceled. At the same time, the algorithm had another detection process. According to the original signal, establish the threshold decision on values of onset points and offset points. Then, the algorithm selected same points combined with singular points which are detected by threshold decision from original signal. Finally, cancel the points which belong to bucket dump and lower segment.

After completed the following stages above, we achieved two points corresponding to onset point and offset point in bucket raise time segment. Calculate time between the two points and then what we achieved above is bucket raise time.

4 RESULT

4.1 Performance of the proposed methodology

The proposed algorithm was realized using MATLAB toolbox and its codes, which was detected based on the signal collected from wheel loader. Results in Table 1 were acceptance and all bucket raise time meets the standards of factory. In the test, bucket raise time detection rate is more than 95% and is still satisfying. Therefore, we could accept the results. In order to satisfy security of factory’s data, the results in the following table are with appropriate changes.
The results shown in Table 1 based on the mathematical algorithm and threshold decision confirmed the ability to discover onset and offset point of bucket raise time segment. Although the mathematical algorithm did not perform very well on signals above the wheel loader total cycling time, the results were still robust, as the unrecognizable rate is less than 5%. We have adjusted the codes for a higher detection data and without leak detection.

Table 1. Bucket raise time results.

<table>
<thead>
<tr>
<th>Data number</th>
<th>Bucket raise time (ms)</th>
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<tbody>
<tr>
<td>1</td>
<td>552</td>
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<tr>
<td>3</td>
<td>557</td>
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<td>6</td>
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<td>48</td>
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</tbody>
</table>

Note: the data was selected randomly by computer.

5 DISCUSSION

5.1 Predominance of the proposed methodology

In this study, the bucket time was successfully detected and the proposed methodology is simple and reliable. The predominance of the proposed methodology is as follows:

1) The process of original signal denoising was omitted. The original signals collected from pressure sensor in factory contain baseline drift and power frequency. In order to enhance the signal, most signal processing methods demanded an appropriate procedure for noise decreasing before signal processing. But in this study, the noise did not influence the results. Cancel the denoising process, reduce calculation in signal processing, and promote detection effectively.

2) The proposed methodology does not have any template. Signal template is crucially essential in some detection algorithm. But the extracted template always costs a lot of time and needs a large amount of calculated quantity in pre-processing. However, the proposed methodology got a quite simple and reliable way to select needed points without any template which improves and simplifies the detection stages. It also ensures the stability of program.

5.2 Deficiency of the proposed methodology

In the study, the proposed methodology also had some deficiencies as follows:

1) The proposed methodology is lack of automatic learning ability. The algorithm codes only follow the steps written in program which is only a mathematical algorithm.

2) The proposed methodology would be appropriate for some kinds of wheel loader. Future work is to expand the flexibility of proposed methodology, and more kinds of wheel loader bucket raise time will be made for identification.

6 CONCLUSION

A robust, reliable and fast algorithm of wheel loader bucket raise time detection was proposed in this paper, which combined wavelet transform with mathematical algorithm. Reliable results had been accepted and accomplished. The threshold decision is applied to select points in original signal and the decision of onset and offset point in bucket raise time segment which let detection simple and effective. Furthermore, this approach is capable of affording accepted results in bucket raise time detection.

In this study, the detection methodology contributed to wheel loader bucket time data collection and data storage which were also a means of truly harnessing the value of science, technology and methodology for the testing technology of factory.

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REFERENCES


